Analysis of geosynthetic tubes filled with several liquids

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Hypotheses

The problem is 2D in nature.

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Hypotheses

The problem is 2D in nature.

The geosynthetic shell is thin, flexible, and has negligible weight per unit length.

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Hypotheses

The problem is 2D in nature.

The geosynthetic shell is thin, flexible, and has negligible weight per unit length.

The material filling the tube is a slurry, and therefore a hydrostatic state of stresses exists inside the tube.

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Hypotheses

The problem is 2D in nature.

The geosynthetic shell is thin, flexible, and has negligible weight per unit length.

The material filling the tube is a slurry, and therefore a hydrostatic state of stresses exists inside the tube.

No shear stresses develop between the slurry and geosynthetic.

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Nomenclature

p – pumping pressure

g – gravitational acceleration

H – tension in geosynthetic

ϱ – specific weight

α – angle between tangent to the tube and y-axis

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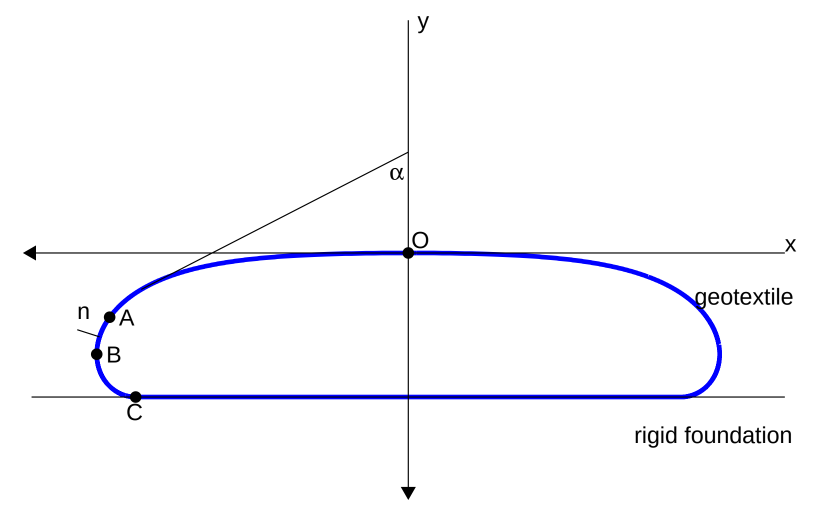
Cross section



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Basic equations

$$\frac{d}{ds}\left(H\frac{dx}{ds}\right)+\frac{dy}{ds}(g\rho y+p)=0,$$

$$\frac{d}{ds}\left(H\frac{dy}{ds}\right)-\frac{dx}{ds}(g\rho y+p)=0,$$

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Problem 1

Let the length of the perimeter $L > 0$ and the pumping pressure $p > 0$ be given.

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Problem 1

Let the length of the perimeter $L > 0$ and the pumping pressure $p > 0$ be given.

Find the values of parameters $H > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$.

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$$\frac{dy}{ds}(s_O) = \frac{dy}{ds}(s_C) = 0,$$

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$$L = 2s_C + 2x(s_C).$$

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Problem 2

Let the length of the perimeter $L > 0$ and the height $h > 0$ be given.

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Let the length of the perimeter $L > 0$ and the height $h > 0$ be given.

Find the values of parameters $H > 0$, $p > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$.

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Find the values of parameters $H > 0$, $p > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$.

$$\frac{dy}{ds}(s_O) = \frac{dy}{ds}(s_C) = 0,$$

$$L = 2s_C + 2x(s_C), .$$

$$h = y(s_C),$$

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Let the length of the perimeter $L > 0$ and the area of the cross section $V > 0$ be given.

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Problem 3

Let the length of the perimeter $L > 0$ and the area of the cross section $V > 0$ be given.

Find the values of parameters $H > 0$, $p > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$.

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Let the length of the perimeter $L > 0$ and the area of the cross section $V > 0$ be given.

Find the values of parameters $H > 0$, $p > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$.

$$\frac{dy}{ds}(s_O) = \frac{dy}{ds}(s_C) = 0,$$

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Let the length of the perimeter $L > 0$ and the area of the cross section $V > 0$ be given.

Find the values of parameters $H > 0$, $p > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$.

$$\frac{dy}{ds}(s_O) = \frac{dy}{ds}(s_C) = 0,$$

$$L = 2s_C + 2x(s_C), .$$

$$V = 2\int_0^{s_C} x\frac{dy}{ds}ds,$$

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Let the pumping pressure $p > 0$ and the height of the tube $h > 0$ be given.

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Problem 4

Let the pumping pressure $p > 0$ and the height of the tube $h > 0$ be given.

Find the values of parameters $H > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$. The value of L is given by

$$L = 2s_C + 2x(s_C).$$

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Problem 4

Let the pumping pressure $p > 0$ and the height of the tube $h > 0$ be given.

Find the values of parameters $H > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$. The value of L is given by

$$L = 2s_C + 2x(s_C).$$

$$\frac{dy}{ds}(s_O) = \frac{dy}{ds}(s_C) = 0,$$

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Problem 4

Let the pumping pressure $p > 0$ and the height of the tube $h > 0$ be given.

Find the values of parameters $H > 0$, $s_C > 0$ and the solutions $x(s)$, $y(s)$ to Basic equations on the interval $(0, s_C)$. The value of L is given by

$$L = 2s_C + 2x(s_C).$$

$$\frac{dy}{ds}(s_O) = \frac{dy}{ds}(s_C) = 0,$$

$$h = y(s_C),$$

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New parameter

$$L(p,H) = 2\int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} \frac{H(1-\sin\theta)d\theta}{(p^2+2g\rho H(1+\sin\theta))^{\frac{1}{2}}}$$

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$$V(p,H) = -2\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \frac{H\sin\theta\,(p^2+4g\rho H)^{\frac{1}{2}}d\theta}{\left(p^2+2g\rho H(1+\sin\theta)\right)^{\frac{1}{2}}g\rho}$$

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$$h(p,H) = \frac{(p^2+4g\rho H)^{\frac{1}{2}}-p}{g\rho}$$

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Theorem 1

Let the positive number $\bar{L}$, $\bar{p}$ be given. Then Problem 1 has exactly one solution.

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Theorem 2

Let the positive number $\bar{L}$, $\bar{h}$ be given and the following inequality

$$\bar{h} < \frac{\bar{L}}{\pi}$$

hold. Then Problem 2 has a solution.

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Theorem 3

Let the positive numbers $\bar{L}$, $\bar{V}$ be given and the following inequality

$$\bar{V} < \frac{\bar{L}^2}{4\pi}$$

hold. Then Problem 3 has a solution.

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Theorem 4

Let the positive number $\bar{h}$, $\bar{p}$ be given. Then Problem 4 has exactly one solution.

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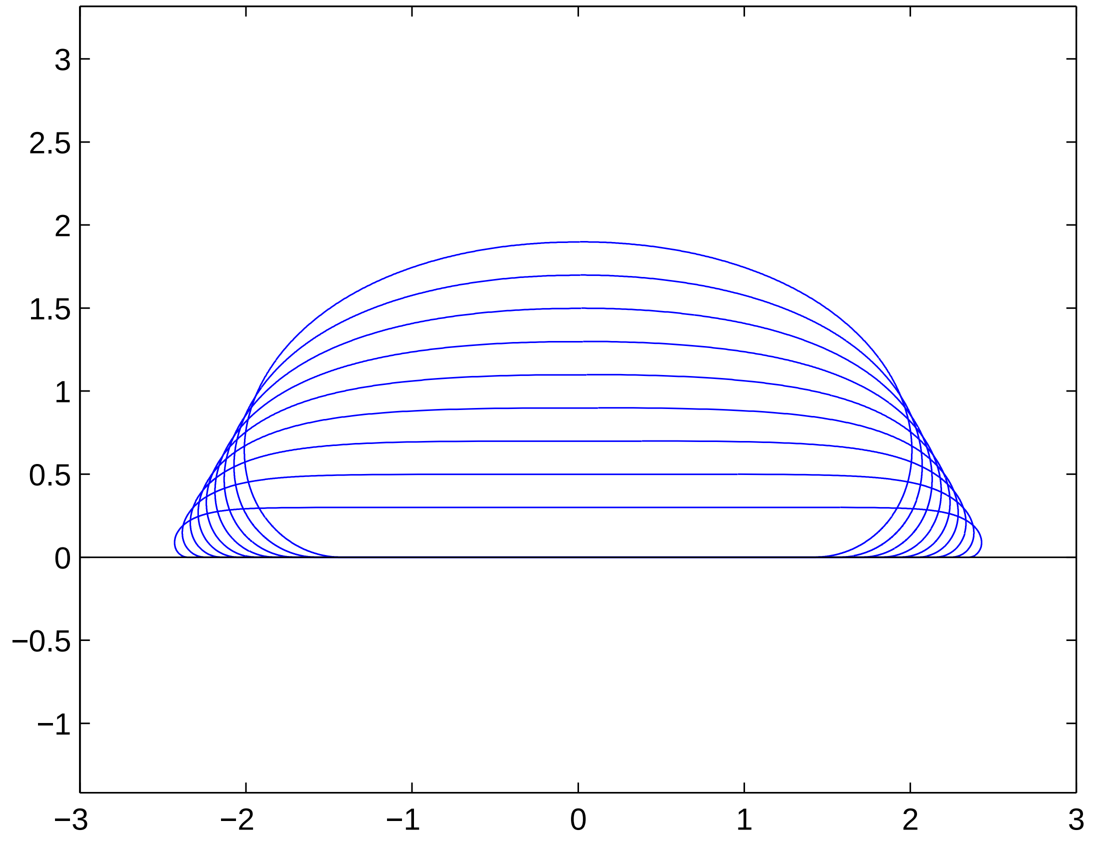

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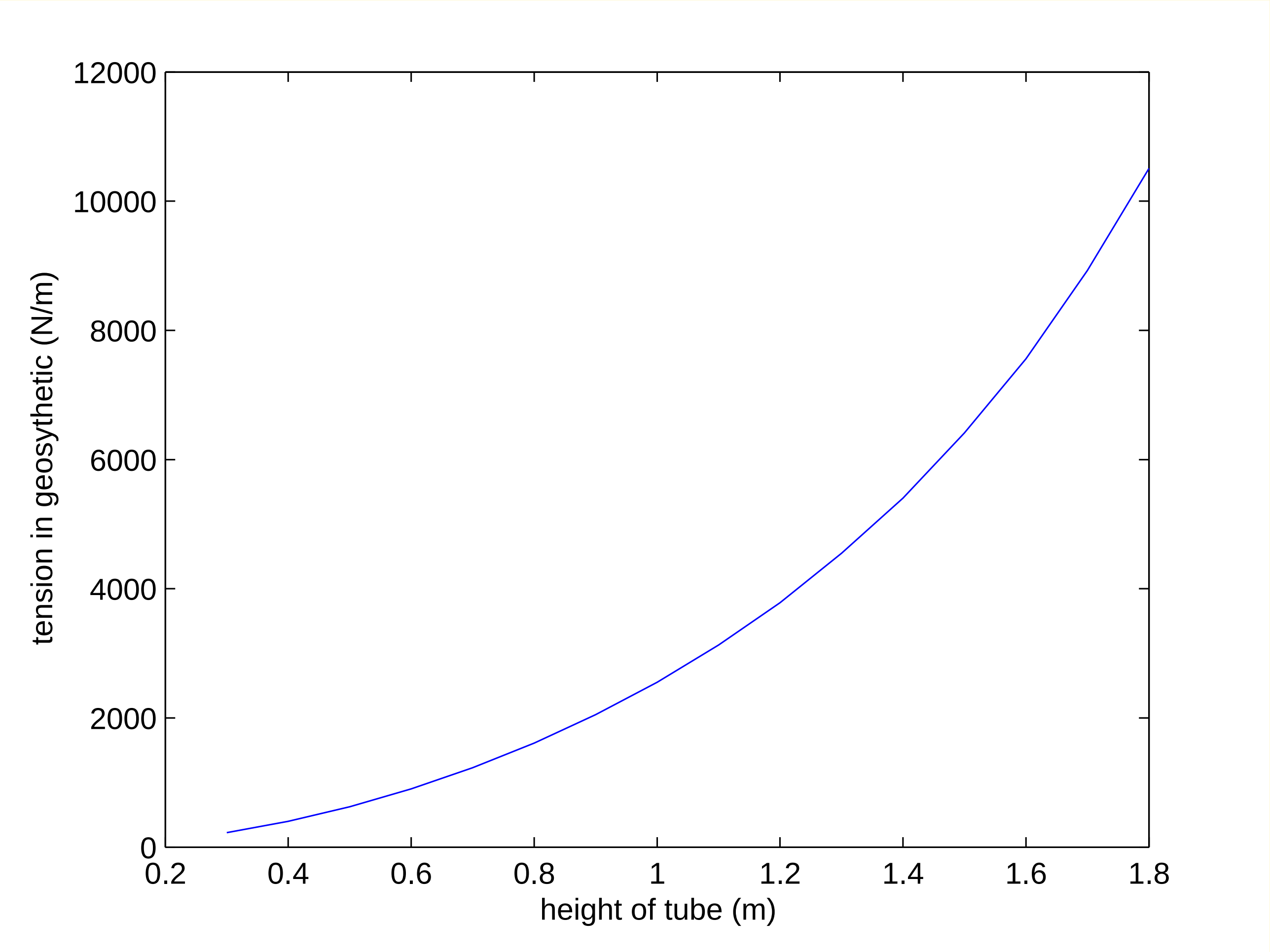

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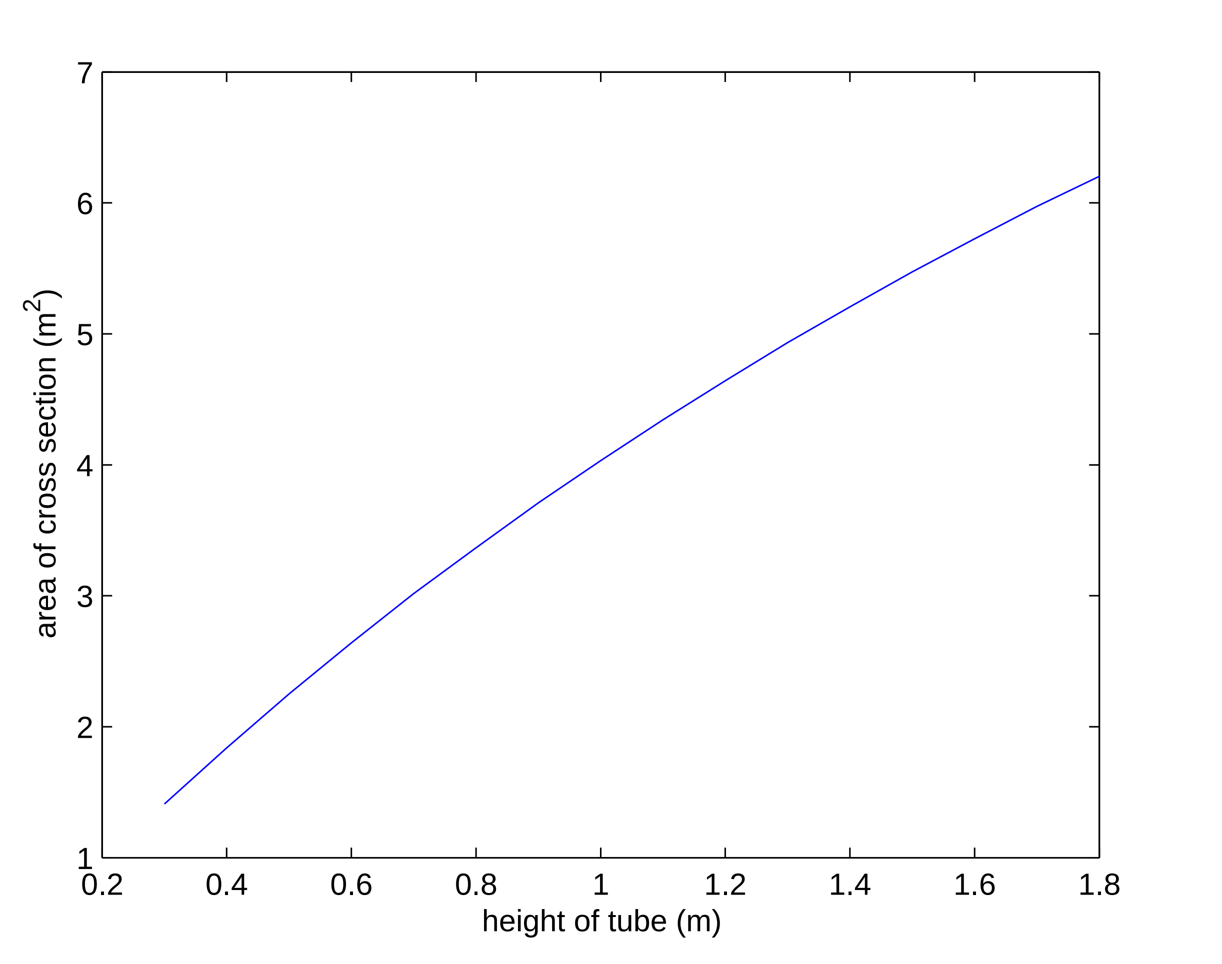

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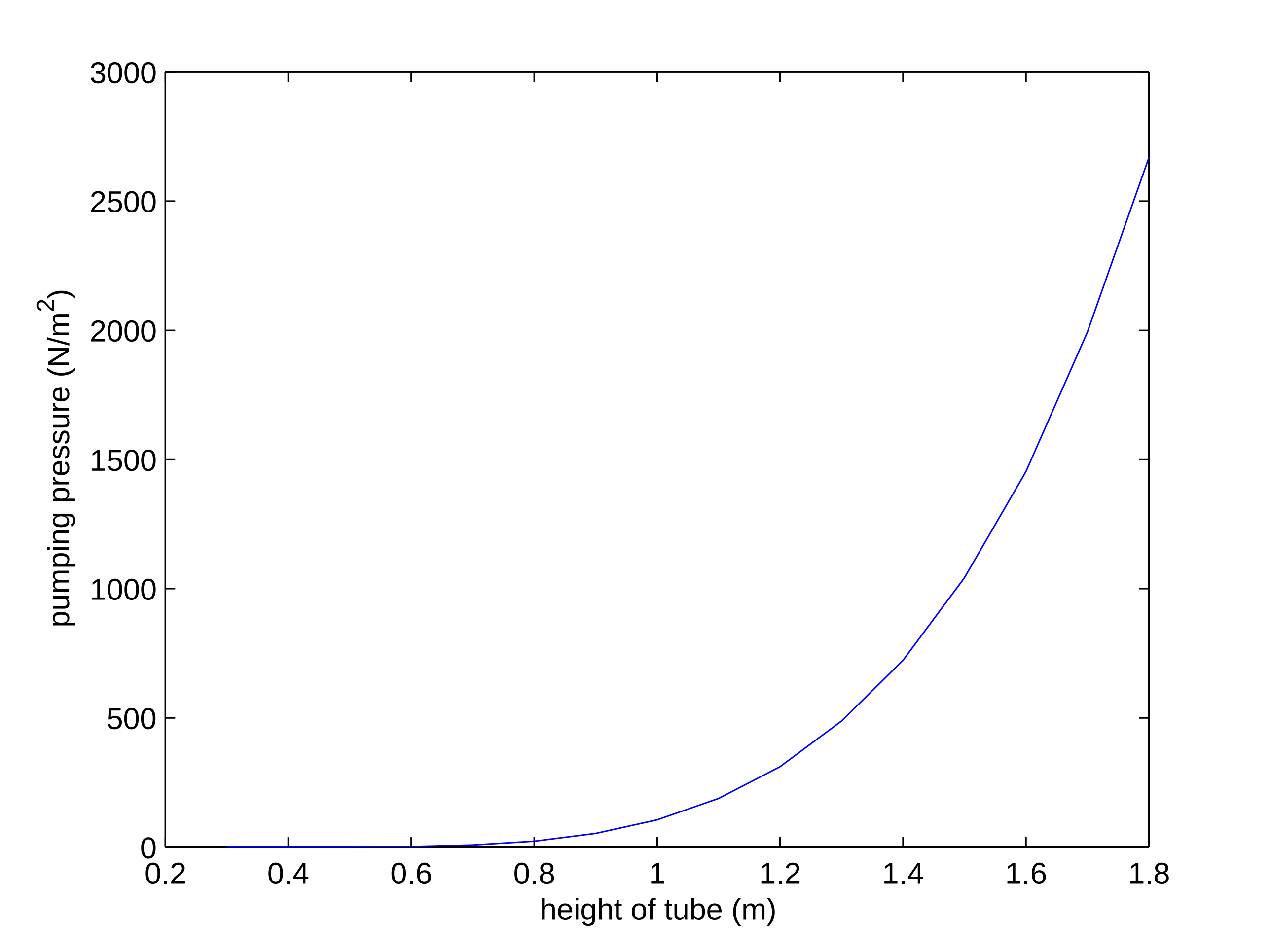

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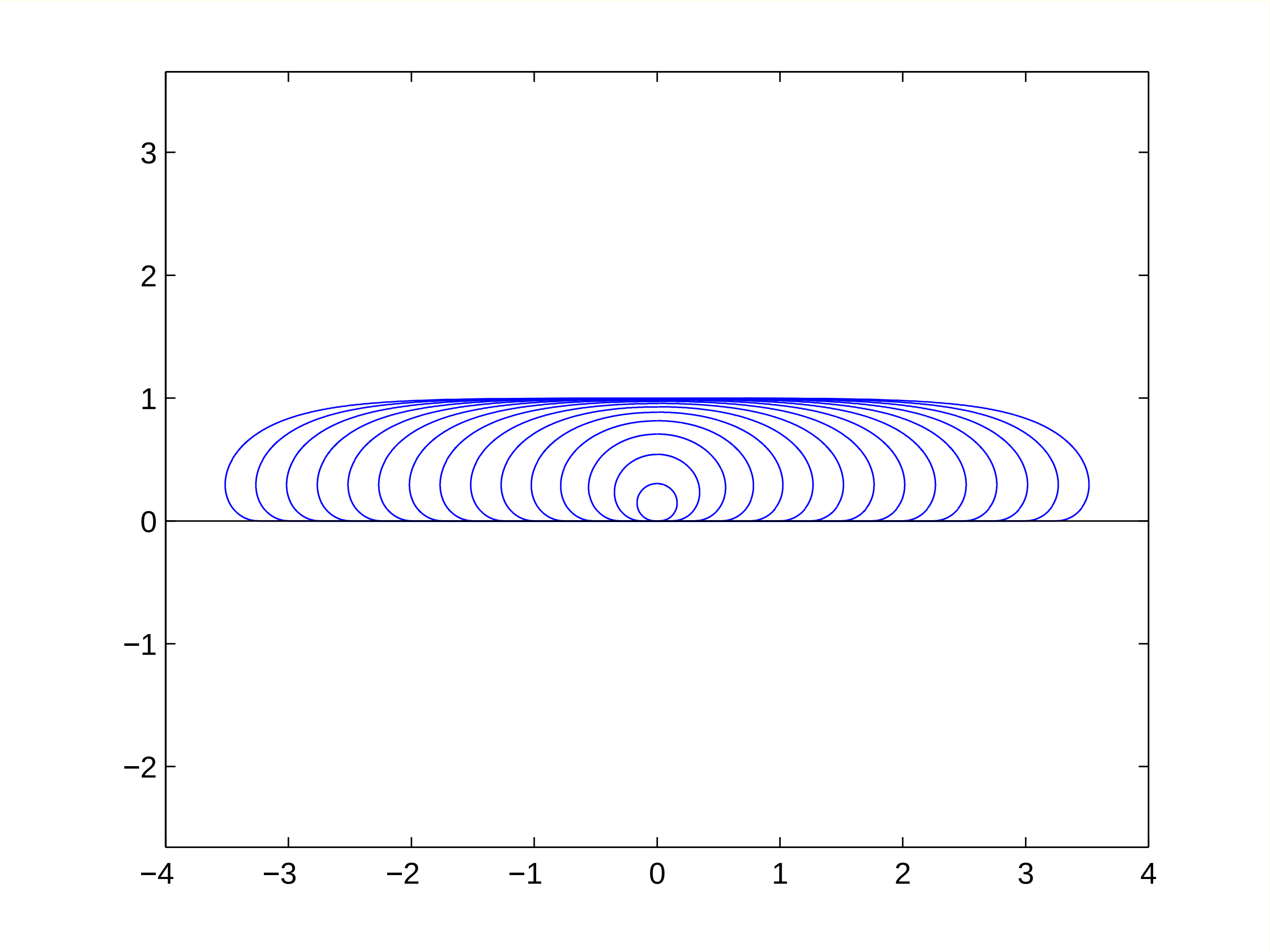

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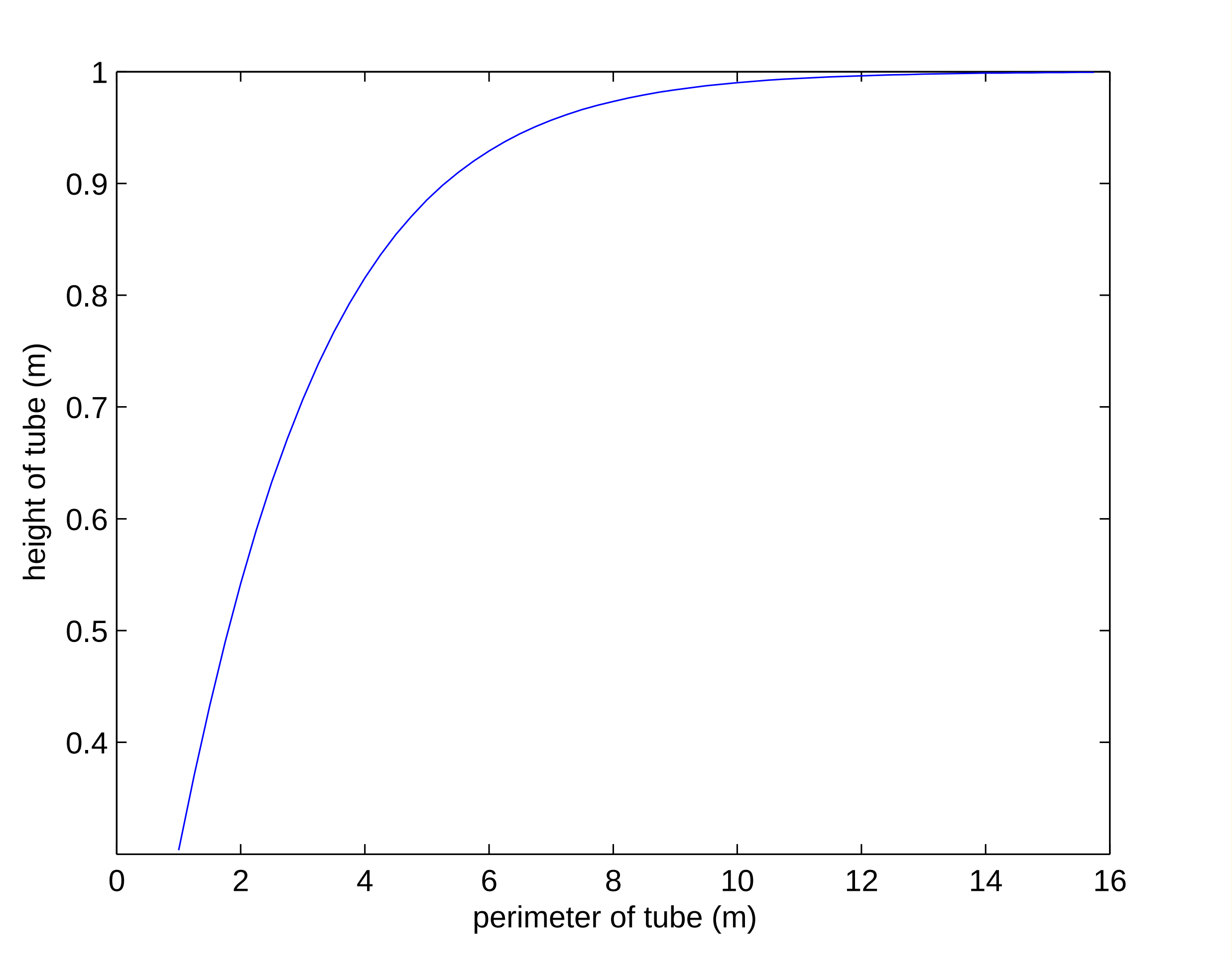

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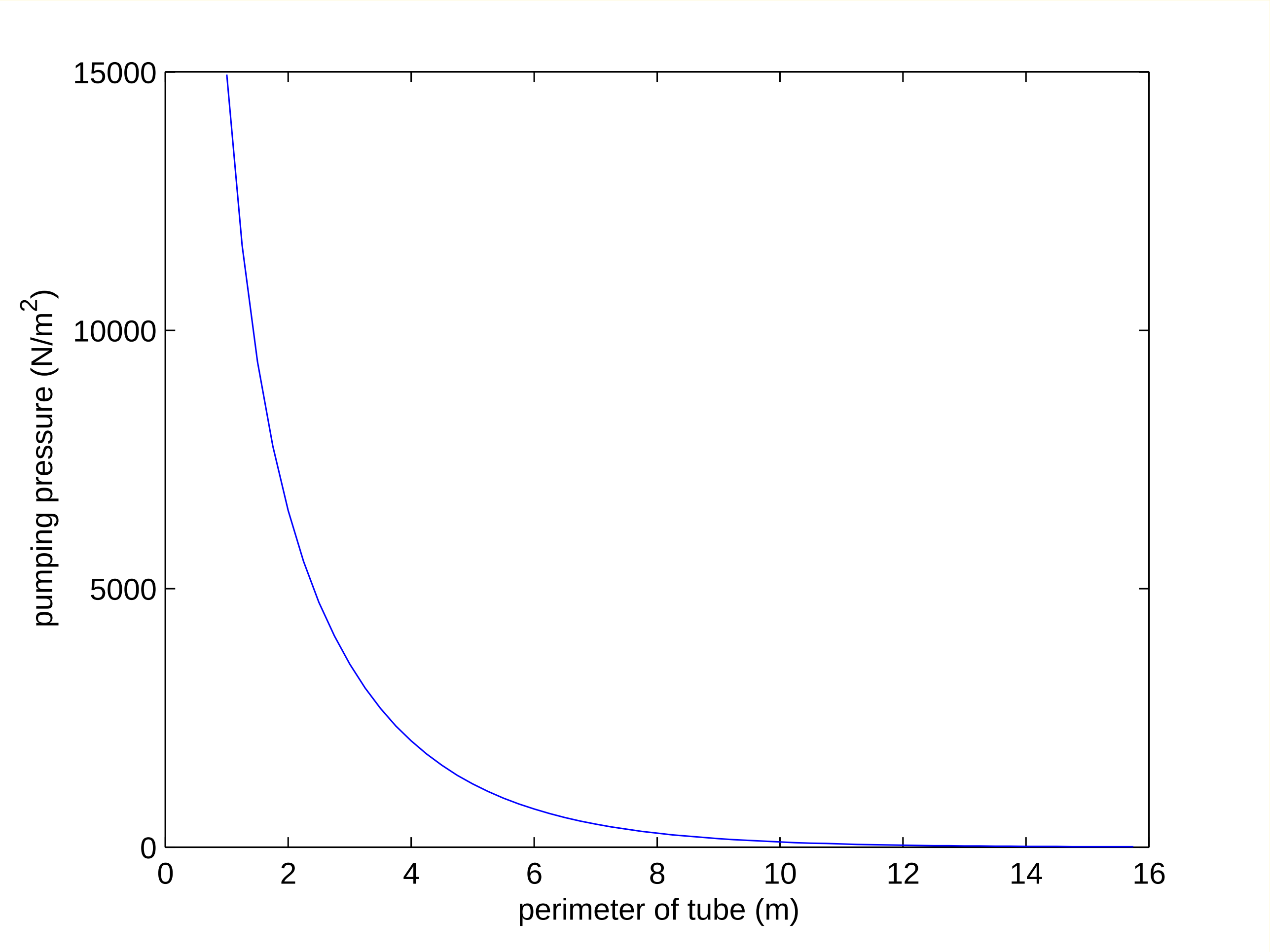

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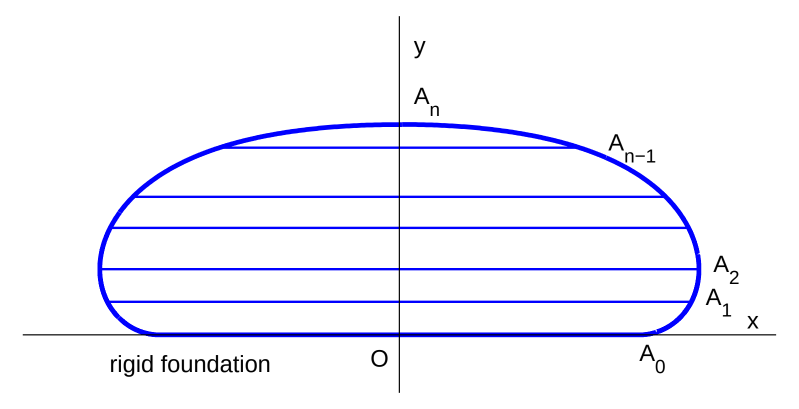

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More liquids - formulation and conditions

$$\rho_1 > \rho_2 > \ldots > \rho_n \, .$$

$$\sum_{i=1}^{n} v_i < \frac{l^2}{4\pi} \, ,$$

$$p_i = p_{i-1} - g\rho_i (y_i - y_{i-1}), \quad i = 1, \ldots, n,$$

$$p_0 > p_1 > \ldots > p_n,$$

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More liquids - basic equations

$$\frac{dx}{ds} = \cos\theta(s)\,,$$

$$\frac{dx}{ds} = \sin\theta(s)\,,$$

$$t\,\frac{d\theta}{ds} = p_i - g\rho_{i+1}(y(s) - y_i)\,, \quad i = 0, 1, \ldots, n-1\,,$$

$$x_n \equiv x(s_n) = 0\,,\ y_0 \equiv y(s_0) = 0\,,$$

$$\theta_0 \equiv \theta(s_0) = 0\,,\ \theta_n \equiv \theta(s_n) = \pi$$

$$s_n = l/2$$

$$\int_{s_{i-1}}^{s_i} x\,\frac{dy}{ds}\,ds = v_i\,, \quad i = 1, \ldots n\,.$$

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$$\frac{dx}{d\theta} = \frac{dx}{ds}\left(\frac{d\theta}{ds}\right)^{-1} = \frac{t\ \cos\theta}{p_i - g\rho_{i+1}(y(\theta) - y_i)}\,,$$

$$\frac{dy}{d\theta} = \frac{dy}{ds}\left(\frac{d\theta}{ds}\right)^{-1} = \frac{t\ \sin\theta}{p_i - g\rho_{i+1}(y(\theta) - y_i)}\,,$$

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$$x(\theta) = x_i + \int_{\theta_i}^{\theta} \frac{t\cos\delta\, d\delta}{\left(p_i^2 + 2tg\rho_{i+1}(\cos\delta - \cos\theta_i)\right)^{\frac{1}{2}}},$$

$$y(\theta) = y_i + \int_{\theta_i}^{\theta} \frac{t\sin\delta\, d\delta}{\left(p_i^2 + 2tg\rho_{i+1}(\cos\delta - \cos\theta_i)\right)^{\frac{1}{2}}},$$

$$s(\theta) = s_i + \int_{\theta_i}^{\theta} \frac{t\, d\delta}{\left(p_i^2 + 2tg\rho_{i+1}(\cos\delta - \cos\theta_i)\right)^{\frac{1}{2}}},$$

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$$\widetilde{x}\,(t,p,\theta',\theta'',\rho)=\int\limits_{\theta'}^{\theta''}\frac{t\cos\delta\,d\delta}{\left(p^2+2tg\rho(\cos\delta-\cos\theta')\right)^{\frac{1}{2}}}\,,$$

$$\widetilde{y}\,(t,p,\theta',\theta'',\rho)=\int\limits_{\theta'}^{\theta''}\frac{t\sin\delta\,d\delta}{\left(p^2+2tg\rho(\cos\delta-\cos\theta')\right)^{\frac{1}{2}}}\,,$$

$$\tilde{l}\,(t,p,\theta',\theta'',\rho)=\int\limits_{\theta'}^{\theta''}\frac{t\,d\delta}{\left(p^2+2tg\rho(\cos\delta-\cos\theta')\right)^{\frac{1}{2}}}\,,$$

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Numerical solution - equations

$$J(z) = 0\,,$$

$$\begin{aligned}
J_i(z) &= x_i - x_{i-1} - \widetilde{x}\,(t, p_{i-1}, \theta_i, \theta_{i-1}, \rho_i)\ , \\
J_{n+i}(z) &= y_i - y_{i-1} - \widetilde{y}\,(t, p_{i-1}, \theta_i, \theta_{i-1}, \rho_i)\ , \\
J_{2n+i}(z) &= v_i/2 - (y_i - y_{i-1})x_{i-1} - \widetilde{v}\,(t, p_{i-1}, \theta_i, \theta_{i-1}, \rho_i)\ , \\
J_{3n+i}(z) &= p_{i-1} - p_i - g\,\rho_i\,(y_i - y_{i-1})\ , \quad i = 1, \ldots, n\,.
\end{aligned}$$

$$\begin{aligned}
J_{4n+1} &= \theta_0\ , \\
J_{4n+2} &= \pi - \theta_n\ , \\
J_{4n+3} &= x_n\ , \\
J_{4n+4} &= y_0\ , \\
J_{4n+5} &= l/2 - \sum_{i=1}^{n} \tilde{l}(t, p_{i-1}, \theta_i, \theta_{i-1}, \rho_i) - x_0\,.
\end{aligned}$$

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Numerical solution - Newton’s method

$$z^{n+1} = z^n - \left(\frac{\partial J(z^n)}{\partial z} \right) J(z^n)$$

$$z^0 = (t^0, p_0^0, \ldots p_n^0, \theta_0^0, \ldots \theta_n^0, x_0^0, \ldots x_n^0, y_0^0, \ldots y_n^0),$$

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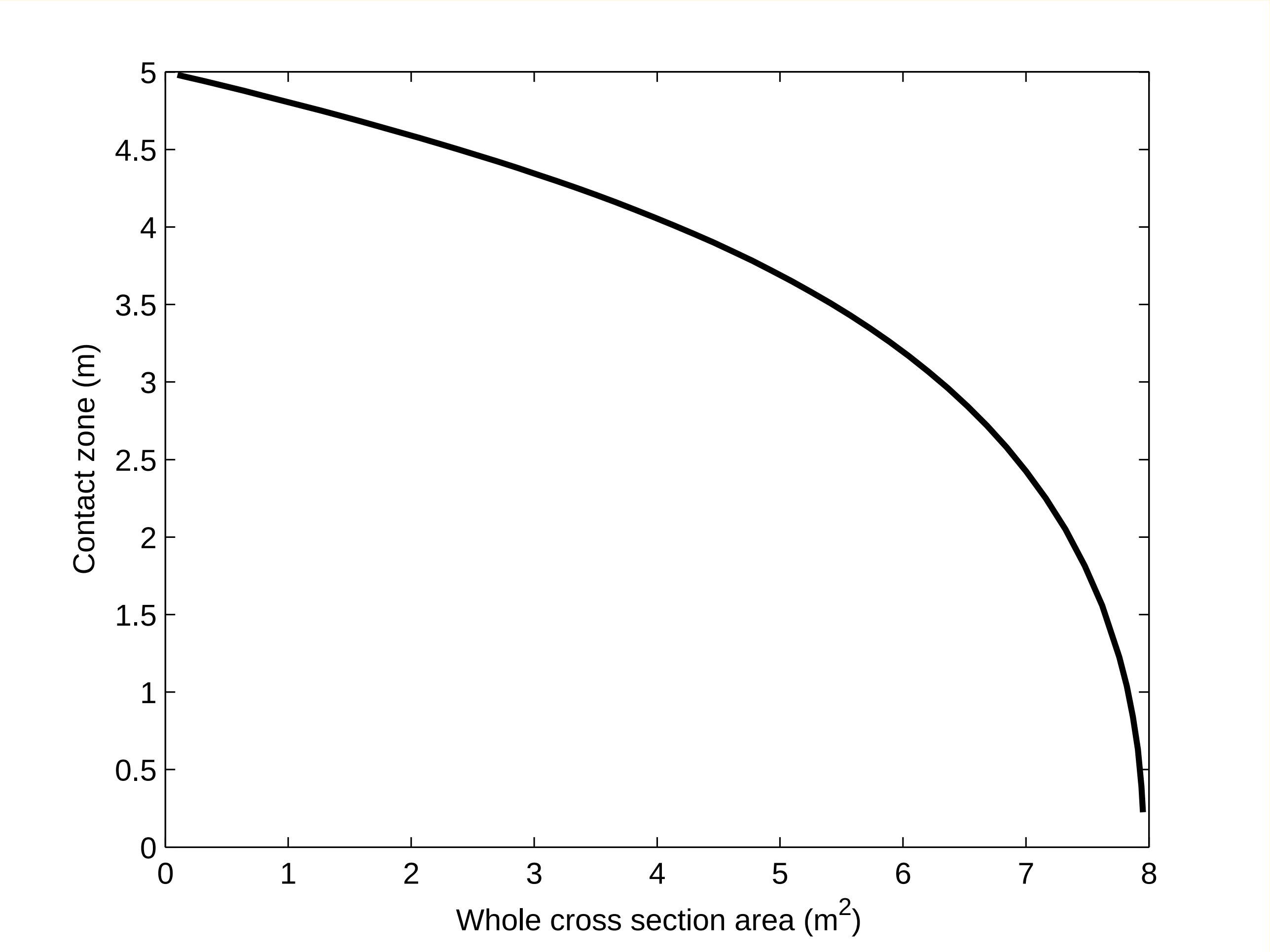
Two liquids - contact zone



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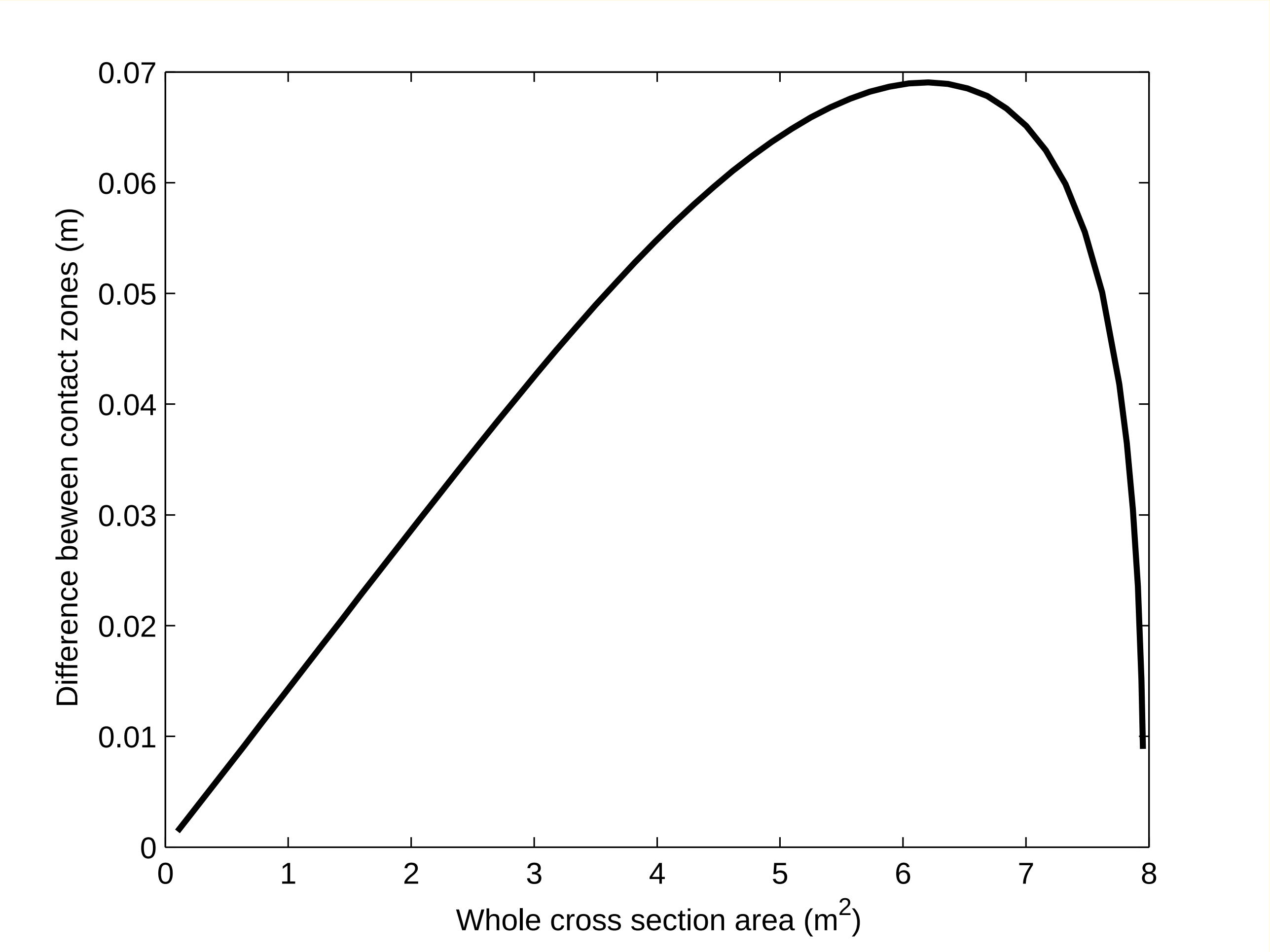

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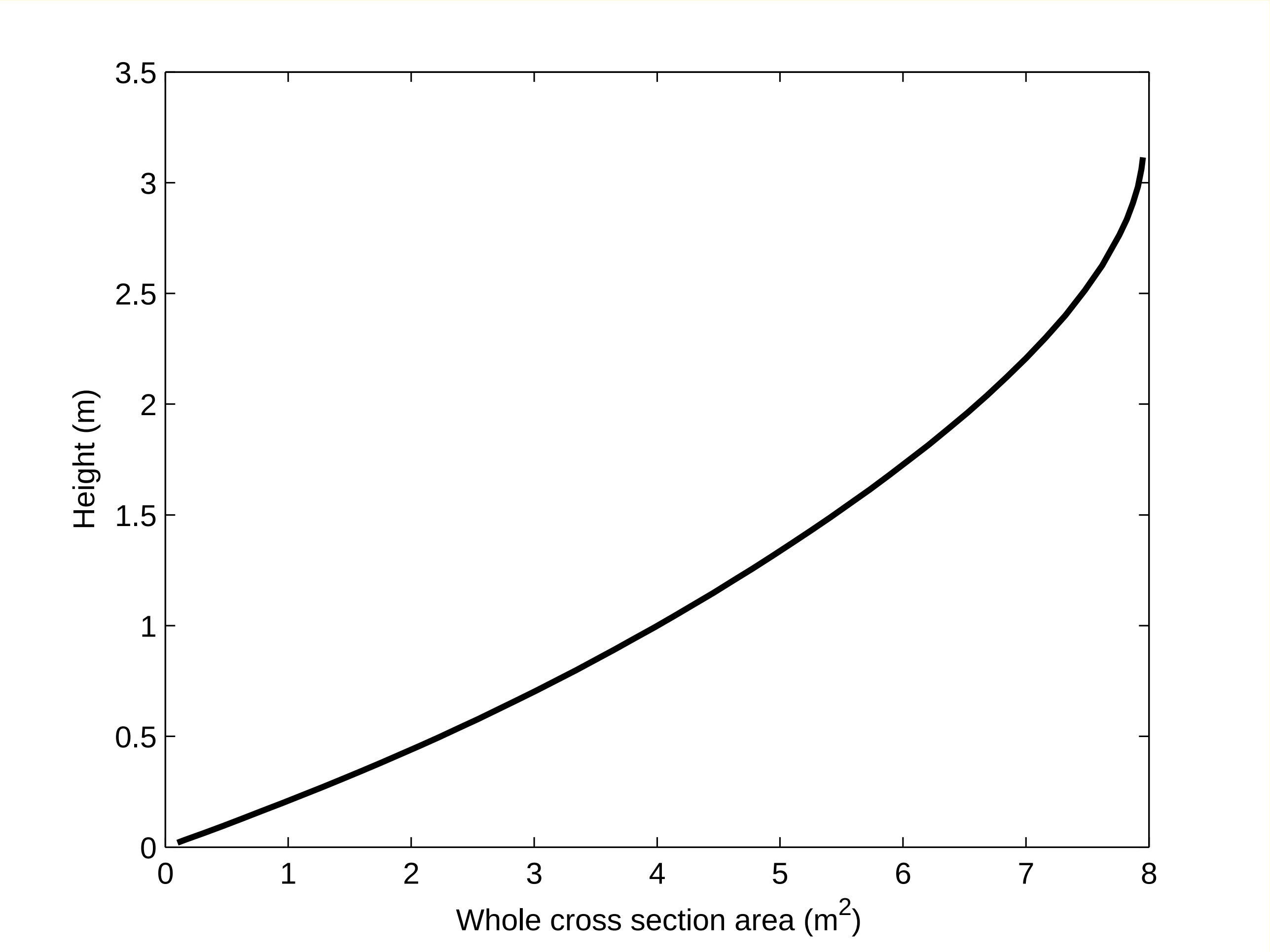

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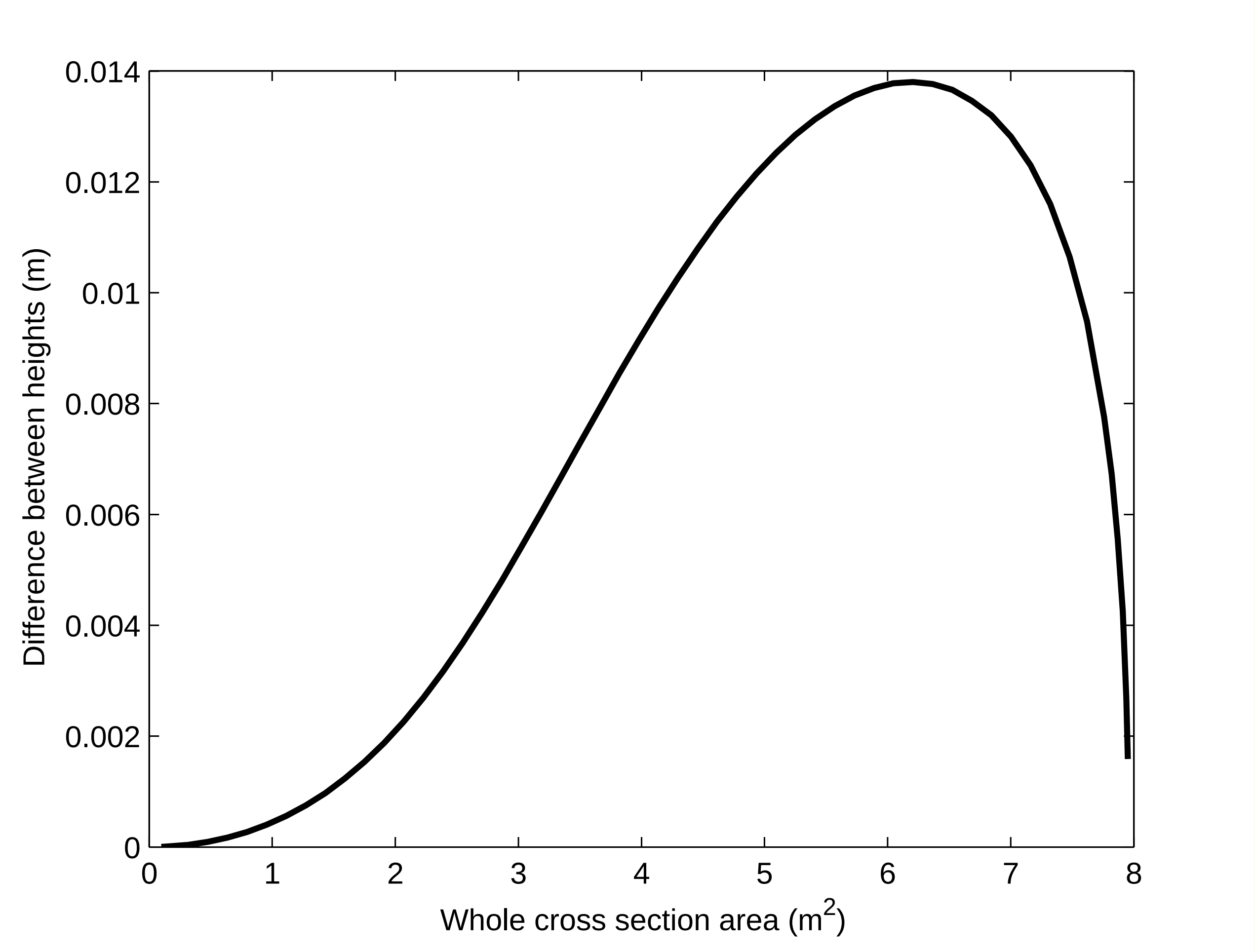

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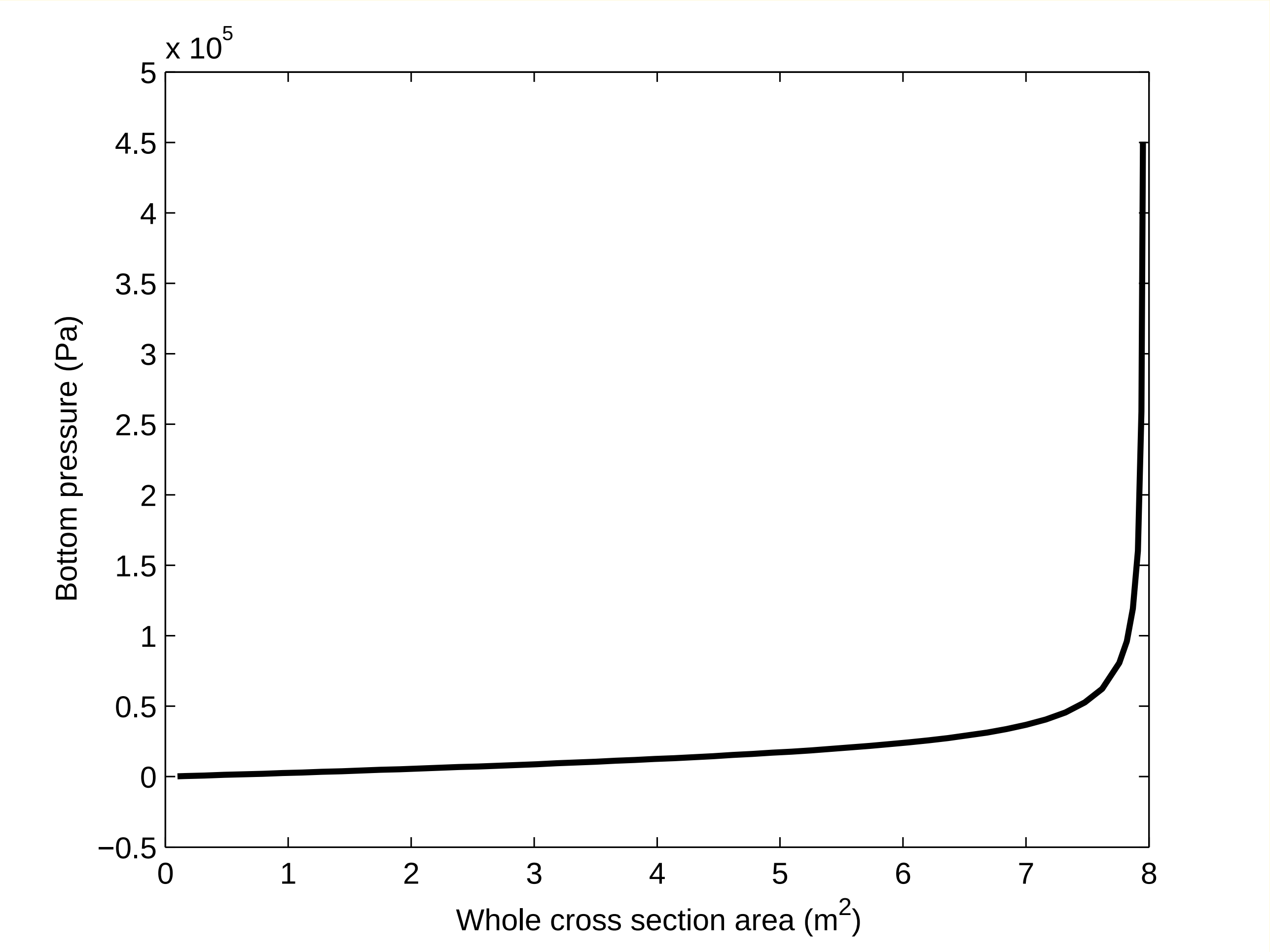
Two liquids - botttom pressure



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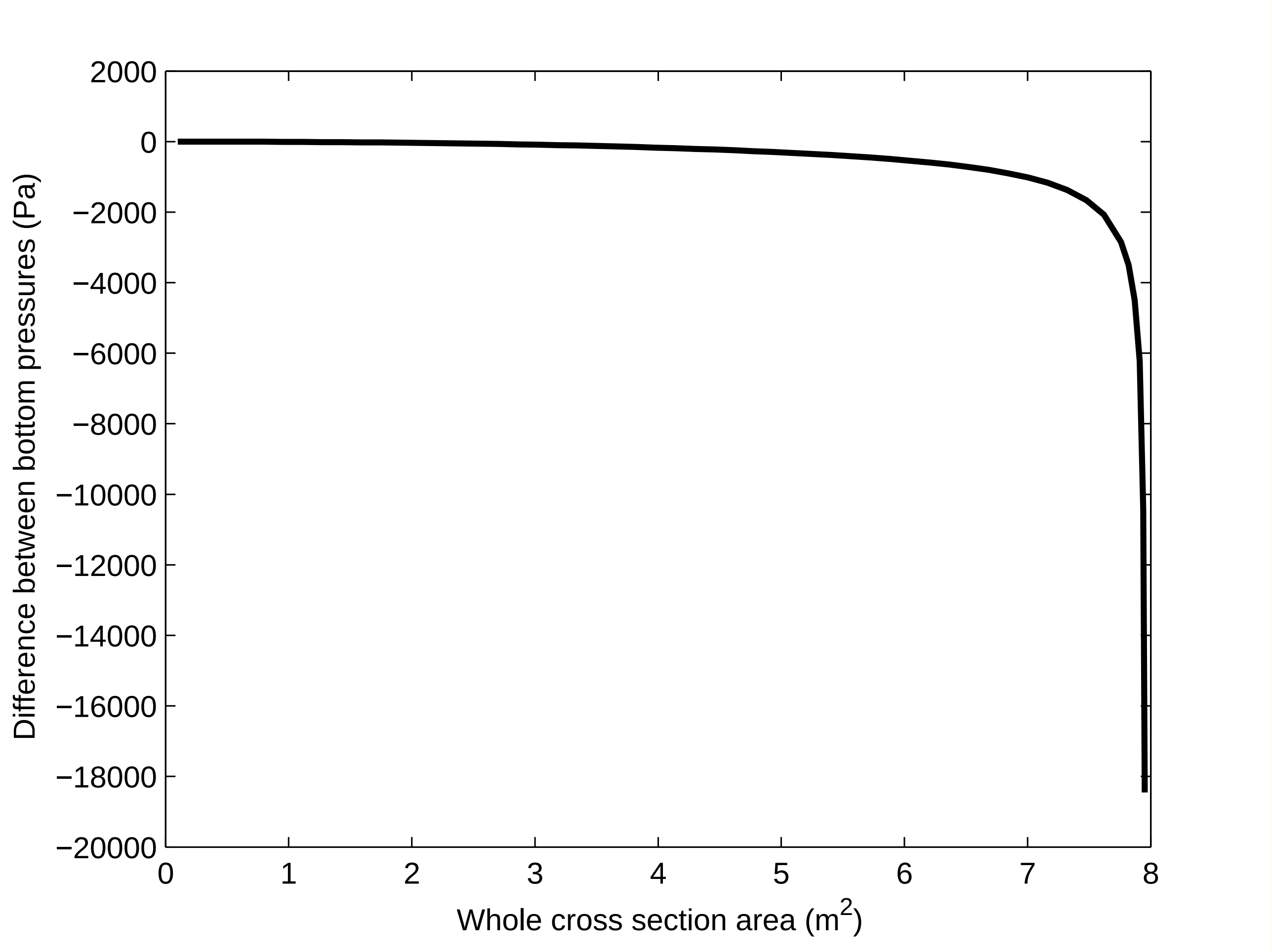
Two liquids - botttom pressure



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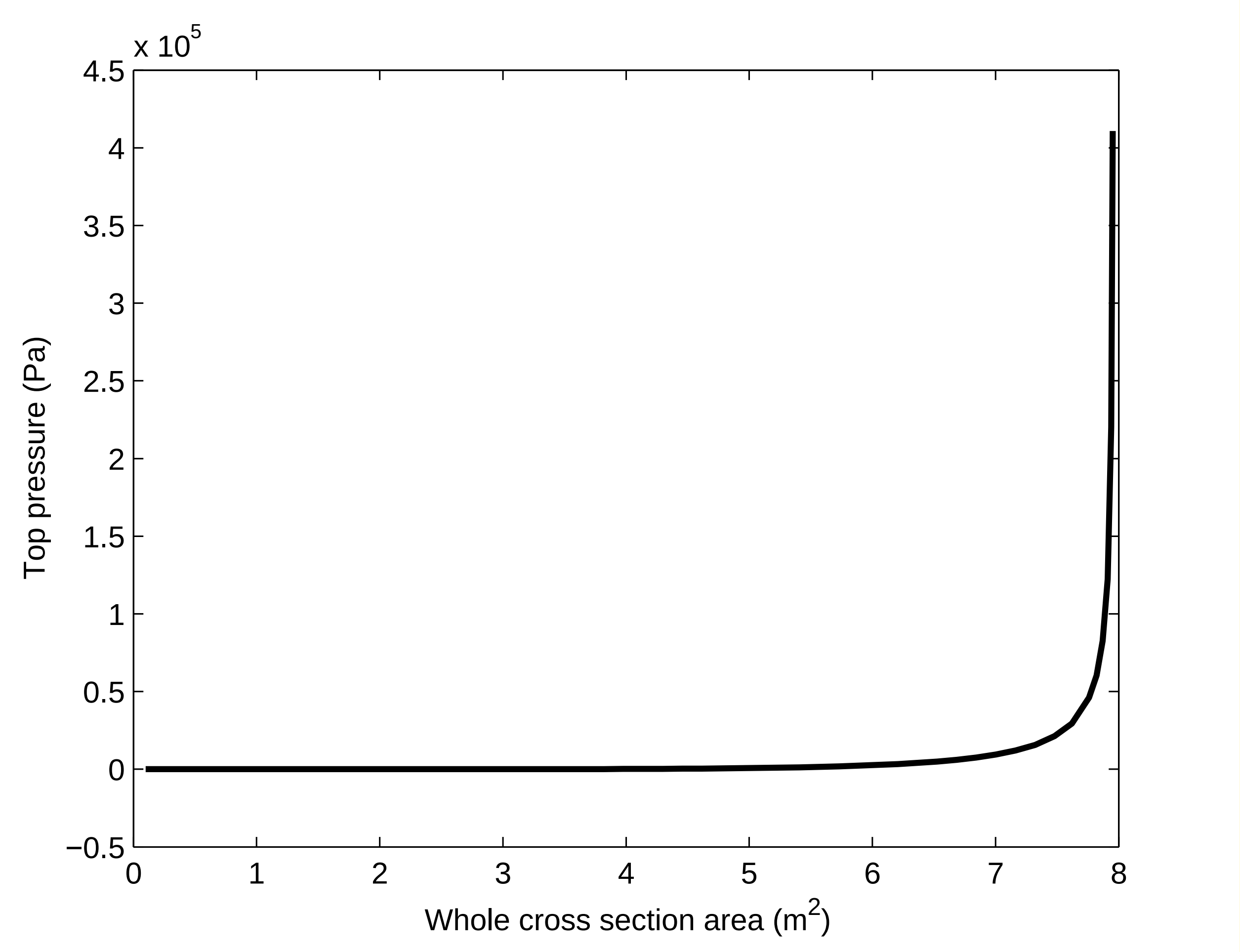
Two liquids - top pressure



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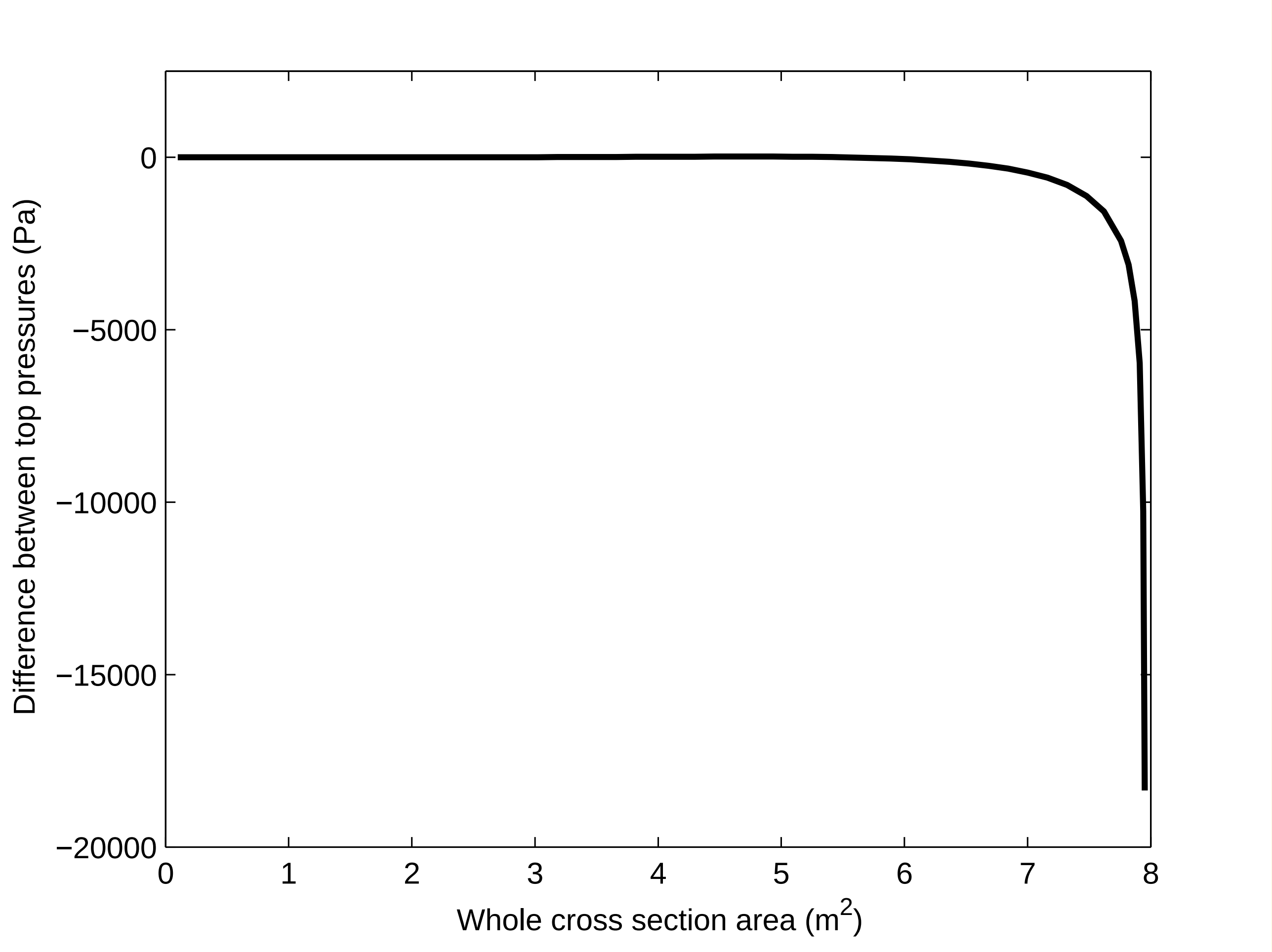
Two liquids - top pressure



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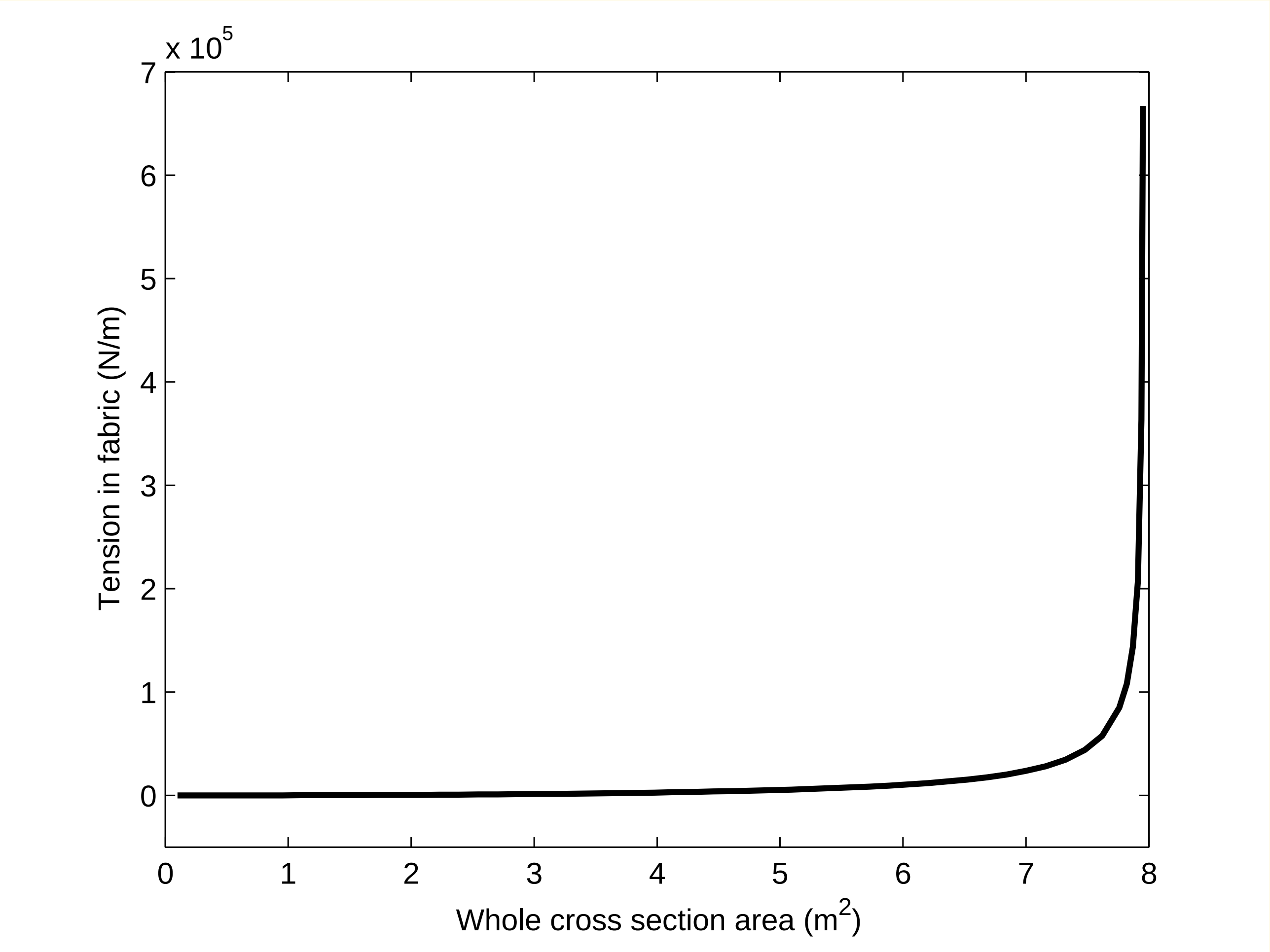
Two liquids - tension in fabrics



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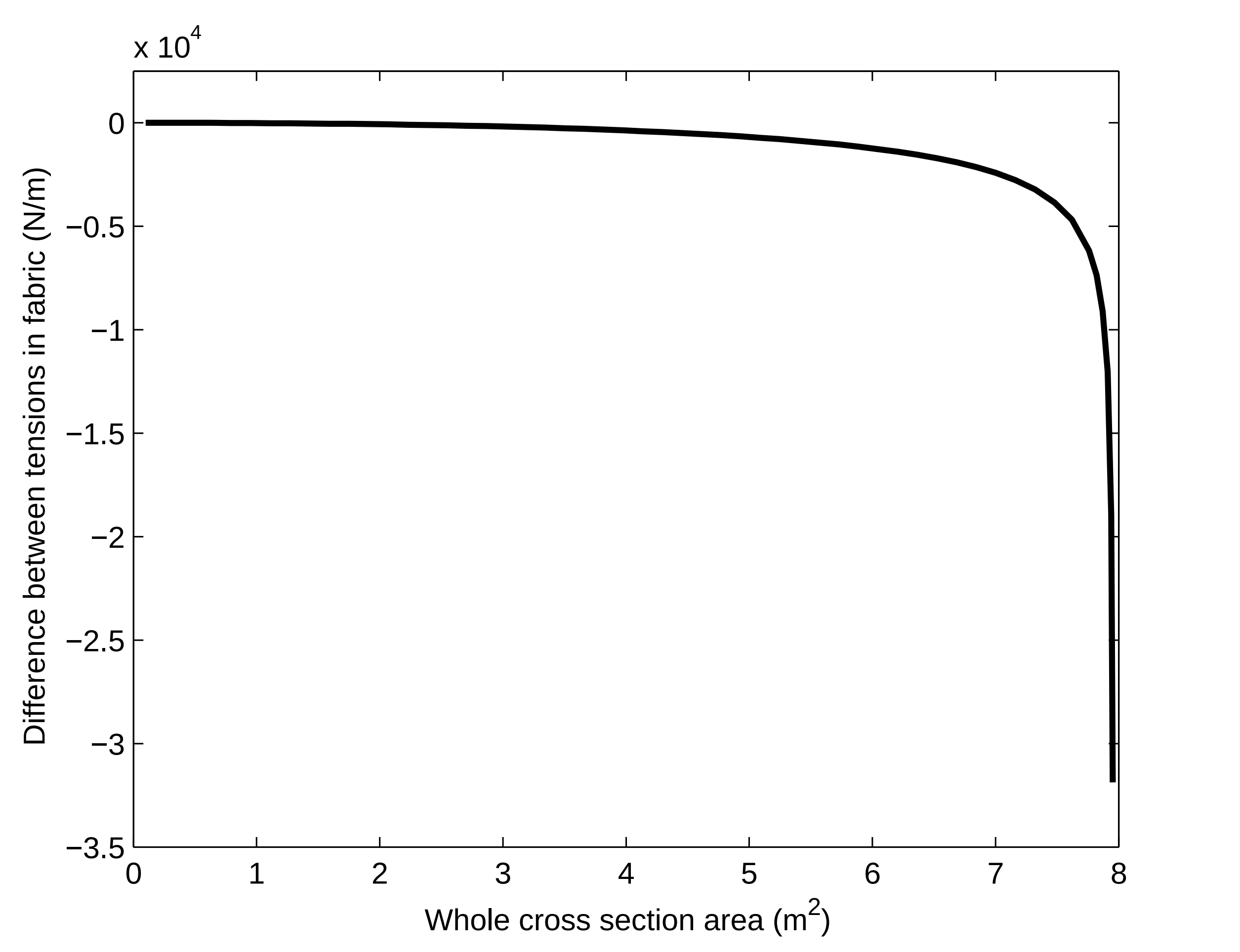
Two liquids - tension in fabrics



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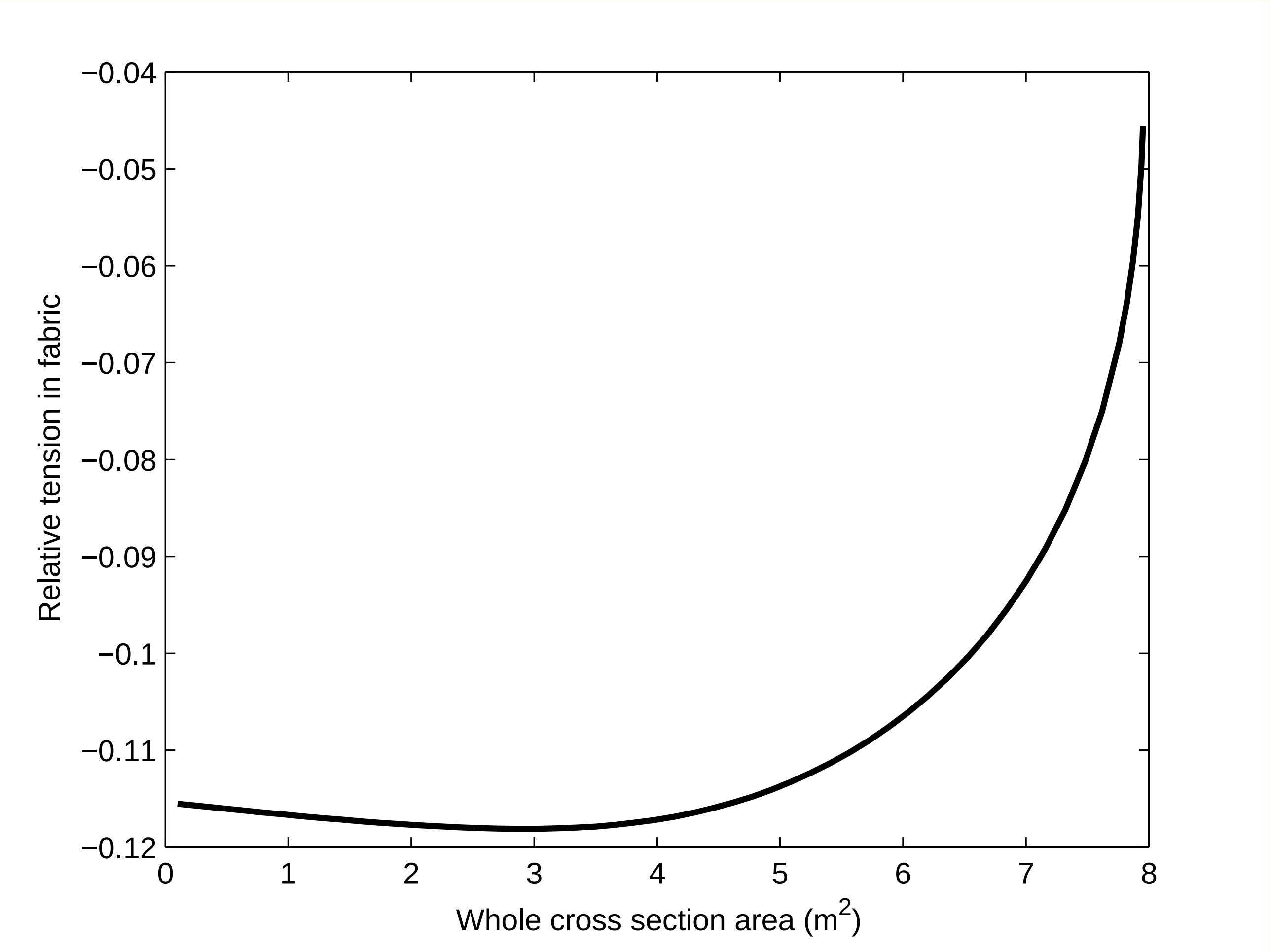

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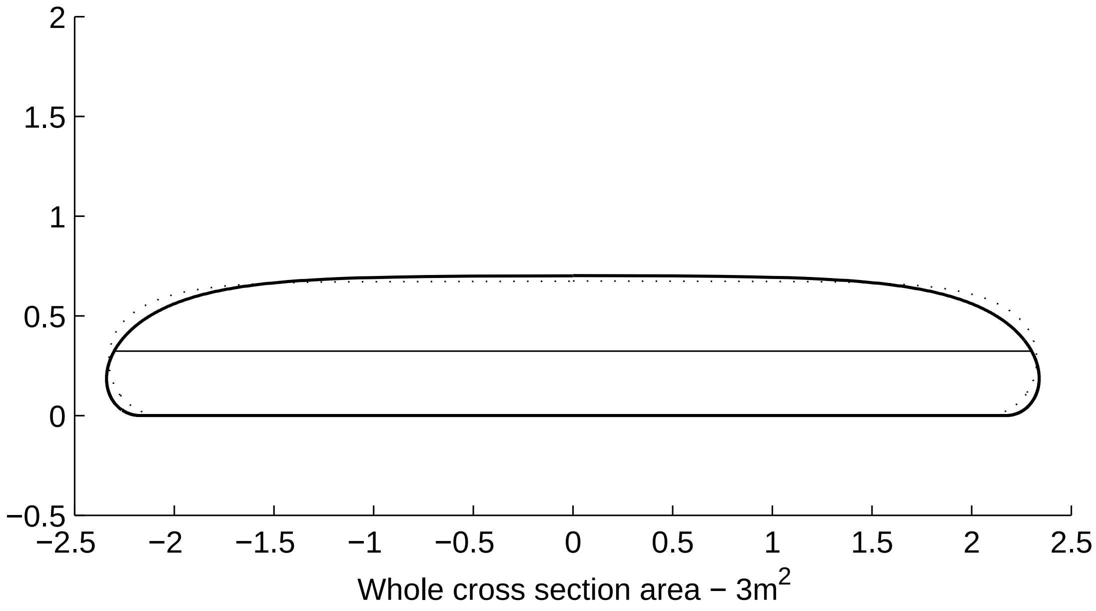

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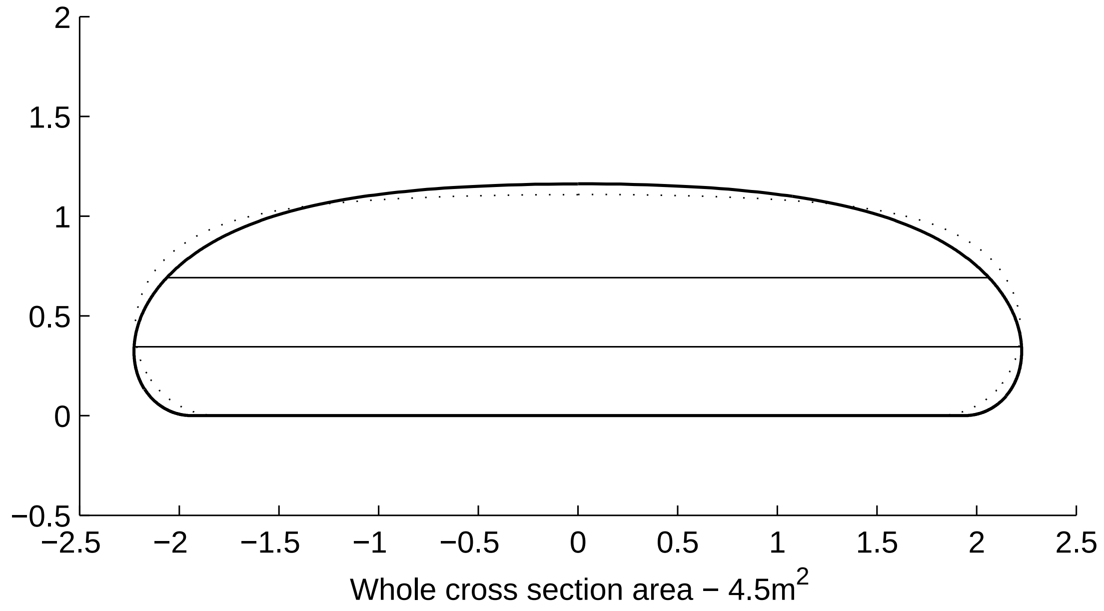

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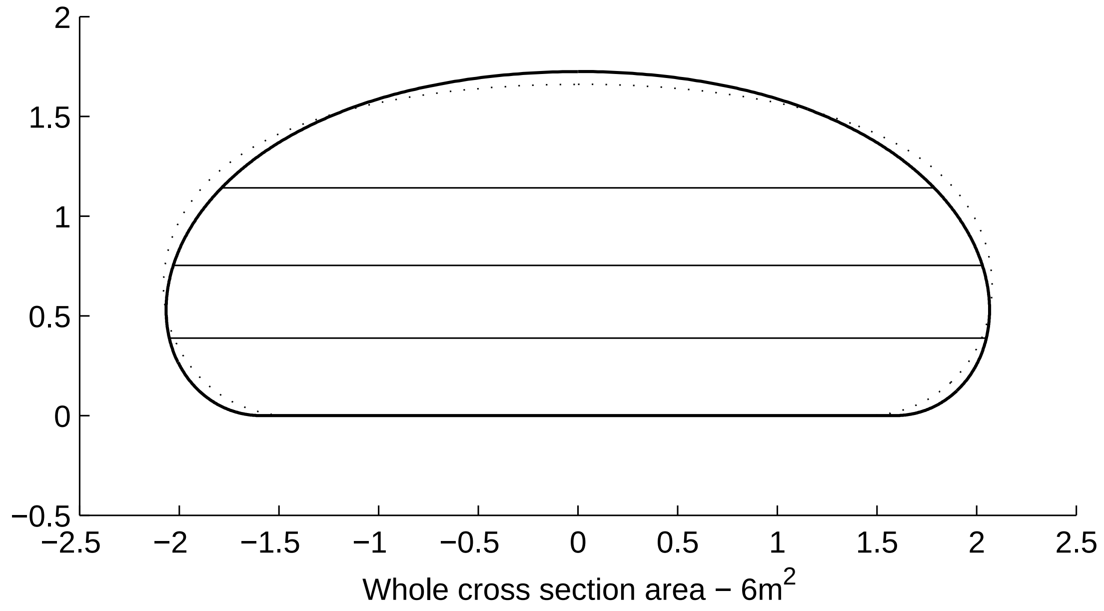

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The dependence between the parameters p, H, L, h, V is nonlinear.

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The dependence between the parameters p, H, L, h, V is nonlinear.

The contact zones are longer.

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The dependence between the parameters p, H, L, h, V is nonlinear.

The contact zones are longer.

The height increases.

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The dependence between the parameters p, H, L, h, V is nonlinear.

The contact zones are longer.

The height increases.

The pressures on the bottom and top are reduced.

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The dependence between the parameters p, H, L, h, V is nonlinear.

The contact zones are longer.

The height increases.

The pressures on the bottom and top are reduced.

The tension force in the fabric is reduced.

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